Evaluating Surface Flux and Boundary Layer Parameterizations in Mesoscale Models Using Measurements from the Japan/East Sea Experiment

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LONG-TERM GOAL

The long-term goal is to improve the surface flux and boundary layer parameterizations in the Navy's operational mesoscale model, COAMPS.

OBJECTIVES

The objective of this research is to systematically evaluate the surface flux and boundary layer parameterizations currently used in COAMPS. In particular, we emphasize intercomparisons between model results and observations in order to understand the model discrepancies.

An added component of the project in late FY01 is to evaluate and improve the prediction of stratocumulus topped boundary layers in COAMPS. We will focus on entrainment and entrainment parameterization in this effort.

APPROACH

My approach is to perform COAMPS simulations on selected cases with the sufficient observations to quantify the marine boundary layer and surface characteristics. This enables us to compare multiple aspects of the boundary layer and near-surface properties between the model outputs and the observations in order to clearly identify the model inadequacy. The model sensitivity to a variety of boundary layer parameters is also tested.

Qing Wang is responsible for the overall project. Dr. John Kalogiros, research associate at NPS, is responsible for observational data analysis. Two scientific visitors, Dr. Kostas Rados and Mr. H. Zuo and one Ph. D. student, LCDR Michelle Whisenhaunt worked on performing and analyses of COAMPS simulations. Direct observations made by the Twin Otter research aircraft operated by the Center for Interdisciplinary Remote Piloted Aircraft Studies (CIRPAS) at the Naval Postgraduate School (NPS) during the Japan/East Sea Experiment (JES, PI: Carl Friehe, UC Irvine) played an important role in our study.

For stratocumulus-topped boundary layer study, we plan to take advantage of the large amount of data collected in the stratocumulus regimes in different regions around the world to first evaluation the current capability in cloud simulation and seek improvements in low-level cloud forecast.

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The long-term goal is to improve the surface flux and boundary layer parameterizations in the Navy???s operational mesoscale model, COAMPS.

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WORK COMPLETED

1. We analyzed the Twin Otter measurements on Feb. 3, 2001 during JES to understand the observed boundary layer mean and turbulence structure under the post-frontal condition as the cold continental airmass was modified through the progressively warm surface of the Japan/East Sea. The measurements of the CIRPAS Twin Otter include multiple soundings and near-surface flux measurements along a horizontal track of the nearly 800 km long flight track across the Japan/East Sea. These measurements made the case ideal for model evaluation. To obtain turbulence fluxes and variances, efforts were made to retrieve the three-dimensional high-rate turbulence (u, v, and w) from the differential pressure and the GPS attitude angle measurements. This was necessary due to a failure of the data system that records the INS attitude angles on this particular flight. All turbulence fluxes and variances for this case were thus derived from the NPS retrieved high-rate turbulence data.

2. We performed a number of COAMPS simulations designed to address a few specific issues regarding parameterizations of surface flux and boundary layer mixing. All COAMPS simulations were made on three-level nested grids with horizontal resolutions of 81 km, 27 km, and 9 km from the outer-most grid to the innermost grid, respectively, with the inner grid covers the entire Japan/East Sea. The COMAPS simulations are briefly described in the following:

(a) *Controlled simulation:* we used the Mellor-Yamada (Mellor and Yamada, 1982) mixing length in the boundary layer parameterization, and original Louis scheme (Louis, 79) for surface parameterization. The horizontal resolution of the terrain database used in the control simulation was 20 km.

(b) *Evaluation on the effects of roughness length*: In the original Louis surface flux parameterization, the roughness heights for sensible and latent heat fluxes were taken simply as 10% of the momentum roughness height. We implemented and tested alternative formulations from Beljaar (1995) where heat and water vapor roughness lengths were calculated in a more complicated way. The impact of this modification is examined through comparisons with the control simulations and with the observed field along the Twin Otter flight track.

(c) *Evaluation on the effects of boundary layer mixing length:* To illustrate and understand the effects of boundary layer mixing on the prediction of surface layer properties and particularly surface fluxes, we designed our third COAMPS simulation with the mixing length by Therry and Lacarrère (1983) to replace the default mixing length by Mellor and Yamada (1982) in the controlled simulation described in (a).

(d) *Evaluation on the effects of coastal terrain resolution:* This issue was addressed by comparing the results from the high-resolution terrain database (1 km) with the controlled simulations.

3. Boundary layer height is a diagnostic variable in COAMPS using a specified bulk Richardson number (0.5 by default) as a criteria. It is frequently used as a measure of the model performance when compared to observations and in some of the boundary layer mixing parameterization. Thus we examined the adequacy of the diagnostic boundary layer height from COAMPS against those hand-picked from the model predicted thermodynamic vertical profiles based on vertical gradient of the corresponding variable. We also tested the sensitivity of the boundary layer height to vertical resolution.

4. The work on stratocumulus modeling with COAMPS started in late FY01. For long-term benefit, we are working on setting up the simulation using the MPI version of the model at the Meteor-

ology Department of NPS. Mean while, I participated in the recent DYCOMS-II experiment and performed preliminary data analysis in preparation for model evaluation.

RESULTS

All results shown are taken from a vertical cross-section along the Twin Otter flight track so that the observed and the simulated results are nominally comparable. Figure 1 shows the observed boundary layer height and wind speed and the COAMPS (controlled simulation and simulation with Beljaar's roughness height). Figure 1 shows that the boundary layer height was well predicted except in regions with relatively low wind speed (~ 5 ms^{-1}) where the boundary layer height is under-predicted by several hundred meters. This region of large discrepancies was found to be most convective based on the Richardson number along the flight track, suggesting the need of improvement for the low-wind convective cases. The wind speed was consistently over-predicted by about 3 ms^{-1}, which is important in explaining the differences in the comparisons of surface fluxes (Fig. 2).

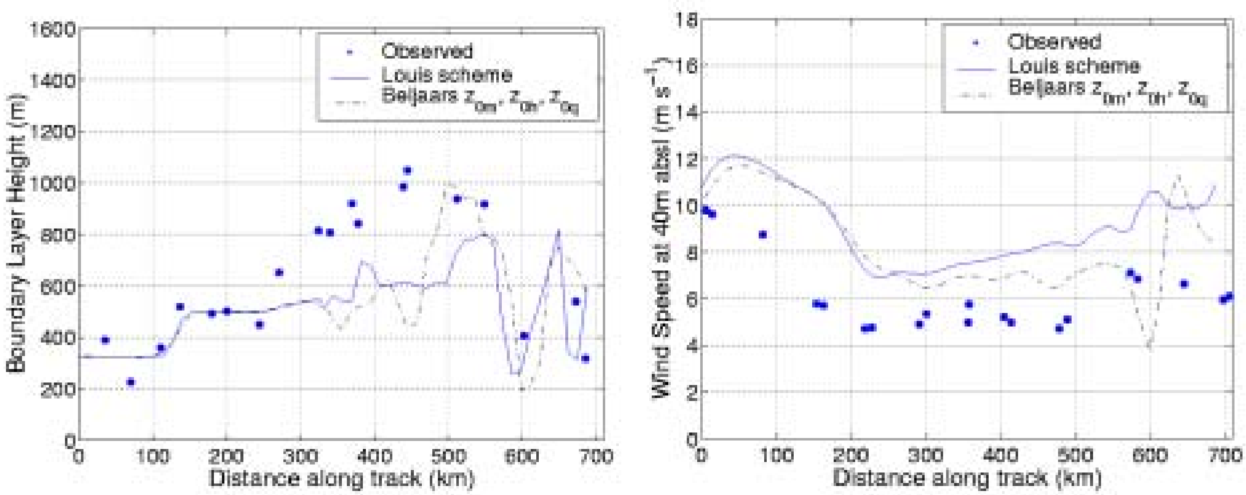

Figure 1. Observed and COAMPS simulated Boundary layer height and wind speed. [left: boundary layer height, right: mean wind speed]

Figure 2 shows COAMPS consistently overestimated the momentum, sensible heat, and latent heat fluxes. We further analysed the sources of discrepancies in the surface fluxes by obtaining the various contributing factors of the exchange coefficients for momentum, sensible heat, and latent heat fluxes (Fig. 3, COAMPS controlled case). The solid and dash lines in Fig. 3 are the total and neutral exchange coefficients from COAMPS, while the symbols denoting stability and gustiness refers to the dimensionless factors from each component. The product of these factors and the neutral drag coefficients results in the total exchange coefficients shown in the solid line. The observed neutral drag coefficient for momentum has large scattering along the flight track, consistent with the notion of larger measurement uncertainty in momentum flux compared to the sensible and latent heat flux (Lenschow and Stankov, 1986). The COAMPS predicted drag coefficient tends to be higher, but not consistently higher. The over-estimated wind stress by COAMPS is thus mainly a result of the overestimated wind speed. For sensible and latent heat fluxes, we found clear trend of over-estimated exchange coefficients (bottom two panels), suggesting the exchange coefficients as a key factor contributing to the dis-

crepancies in these fluxes. In addition, the discrepancies in the neutral exchange coefficients point to unrealistic representation of the surface roughness lengths.

The simulation with Beljaar's roughness length formulation introduced changes in all three fluxes, particularly over regions with high sea surface temperature. However, it is not clear that these changes are improvements, especially in sensible and latent heat fluxes (Fig. 2) since the deviation from observation is not consistently decreased. However, our analysis in Fig. 3 clearly indicates the uncertainty

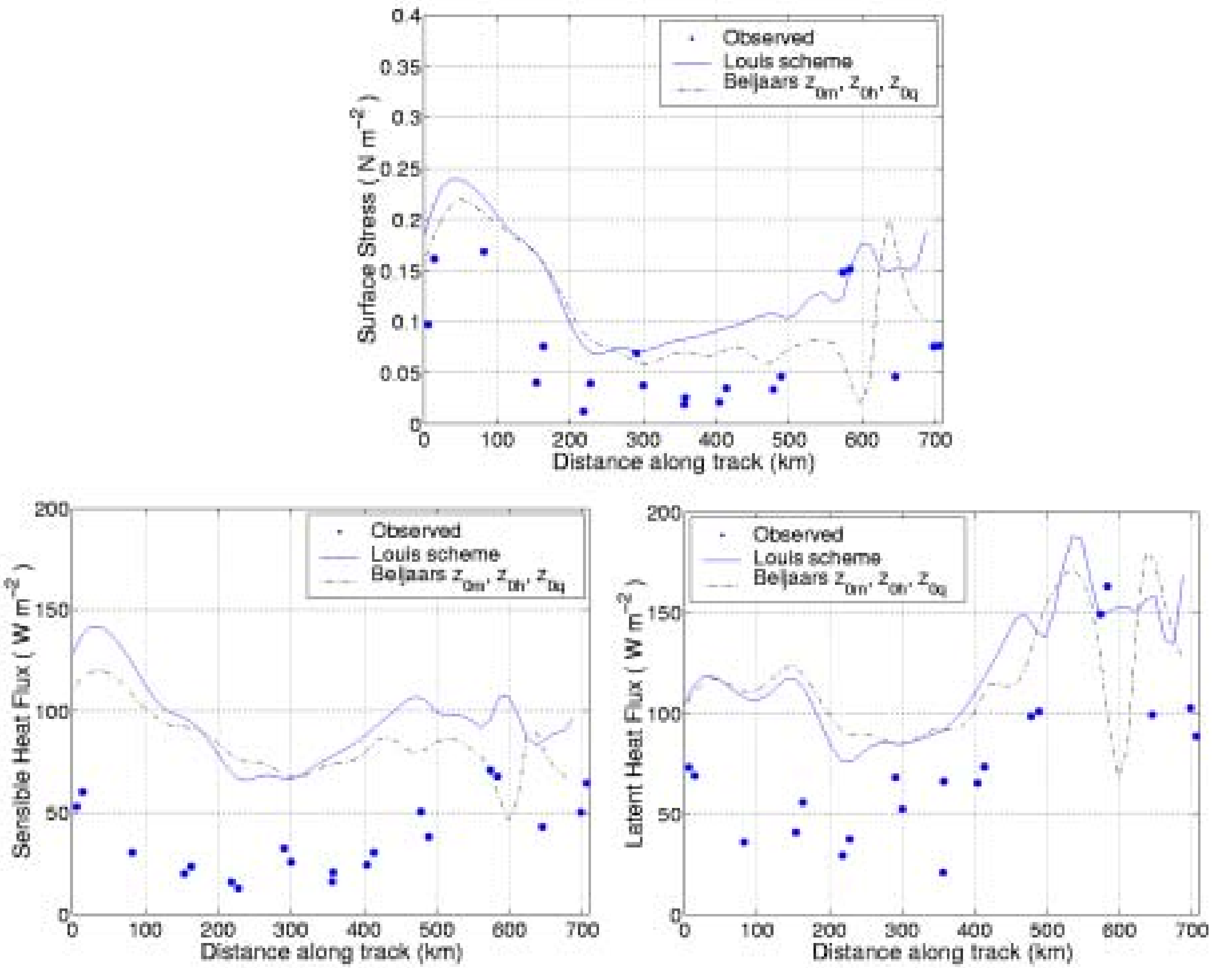

Figure 2. Comparisons of COAMPS and the observed surface fluxes.

in roughness length. Testing for effective roughness length formulation will thus continue to the focal point of our future effort to improve the COAMPS prediction for surface flux.

Surface fluxes are rather sensitive to the formulation of mixing length. The difference can be as large as 50%, especially for the coarser grid. An important task in improving surface flux parameterization is thus to improve the boundary layer mixing parameterization as well, as the two components are nonlinearly related.

The work on diagnostic boundary layer height suggested that the Richardson approach was in general valid. However, we found strong sensitivity of the COAMPS diagnosed boundary layer height to vertical grid resolution. Our simulation with 50 layers in the boundary layer showed significant improvements in predicting boundary layer height compared to the 30 vertical levels run in the controlled simulation.

For the JES cases, because of the steep terrain feature on the Korean peninsula, the use of high-resolution terrain data significantly reduced the surface wind speed and the surface stress, especially near the coastal region. Surface heat fluxes are modified towards the observed values as well.

IMPACT/APPLICATIONS

Our analyses of observational and model results point to the need of improved roughness length used in Louis scheme in order to improve the representation of surface flux in COAMPS. This major conclusion will be verified with more simulations for other cases in JES. From there we will test other existing roughness length formulations or develop our own to improve the original Louis flux parameterization.

TRANSITIONS

The improved surface flux parameterization will be submitted to NRL for further testing for possible transition to the operational COAMPS. I also plan on such transition for the new component in this project: the implementation of explicit entrainment parameterization in COAMPS.

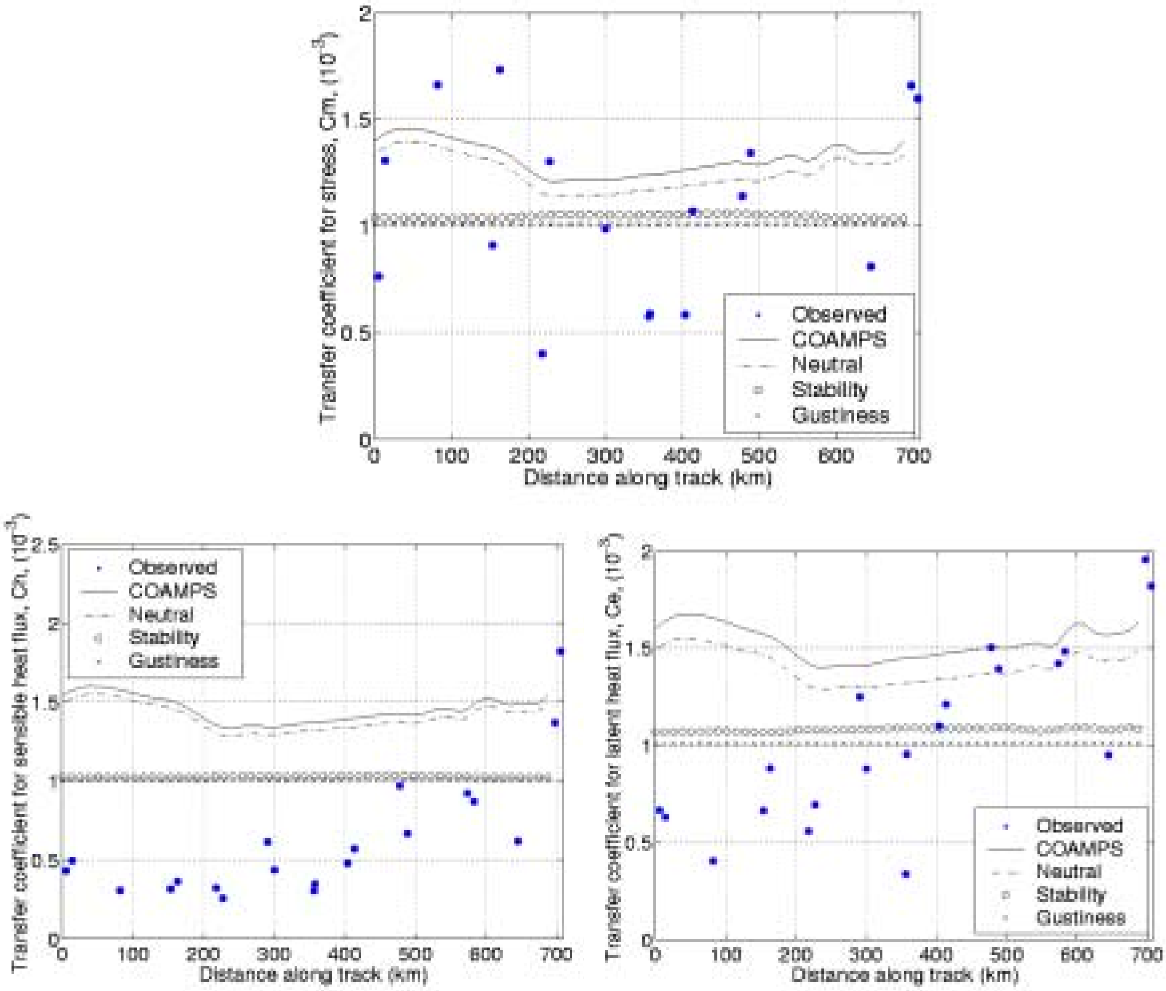

Figure 3. Comparisons of COAMPS exchange coefficients and stability and gustiness factor in these coefficients.

RELATED PROJECTS

Related projects is N001400WX20757(B), for *Advanced Surface Flux Parameterization.*

SUMMARY

We performed systematic evaluation of the COAMPS simulations for a case observed during JES in post-frontal airmass modification conditions. With the complicated nonlinearly interactions within the mesoscale model, our study points to the inadequacy of the neutral exchange coefficient of heat and water vapor (and thus the roughness length) as the key source of uncertainty. Initial attempt to improve the roughness length with the Beljaar formulation is unsatisfactory and leaves the work in this direction in the future. From other designed simulations, we also quantified the effects of boundary layer mixing length and resolution of surface terrain on surface fluxes.

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